A Study on the Various Volume Reducing Methods for Wasted EPS Foam

Joong-Yeon Lim[1], Ho-Joon Choi[2] and Beong-Bok Hwang[3]

[1]Department of Mechanical Engineering, Dongguk University
[2]Department of Automation Engineering, Inha University
[3]Department of Mechanical Engineering, Inha University
253 Younghyun-Dong, Nam-Gu, Inchon 402-751, Korea

Abstract

Current volume reduction methods for wasted expandable polystyrene (EPS) foam are summarized and compared each other. Wasted EPS foam has not been recycled effectively because of its large volume to weight ratio. This has prevented from its proper recycling because of high cost of transportation to recycling plant. Successful recycling of wasted EPS foam results directly from successful, i.e. economically and environmentally, volume reduction of wasted EPS foam. This paper deals with various methods for volume reduction methods of wasted EPS foam. Five typical methods of volume reduction are introduced and they are compared each other in terms of expected PS properties after volume reduction, cost effectiveness of each process, possible effects on environment caused by the volume reduction process, and possible recycled products. The methods include thermal, solvent, far infrared and mechanical compaction. Comparison in this paper is made mostly in qualitative manner. The focus in this study is concentrated on summarizing and comparing existing methods of volume reduction for wasted EPS foam.

Key words: wasted expandable polystyrene (EPS), high volume to weight ratio, volume reduction, recycling, PS properties, cost effectiveness

1. Introduction

Styrene, a petroleum by-product, is the primary raw material from which polystyrene (PS) is made. Synthetic styrene, i.e. polystyrene, is the common name for the alkene polymer styrene with the repeating formula $H_2C{=}CHC_6H_5$ where C_6H_5 is a phenyl group which is comprised of a benzene ring with one hydrogen atom removed. This synthetic styrene is used in the manufacture of products such as automobile parts, electronic components, synthetic rubbers, and especially expanded polystyrene (EPS) foam for product packaging. Expandable polystyrene is the raw material or resin for the molding of expanded polystyrene products. It is manufactured in the form of very small polystyrene beads with a molecular weight between 160,000 and 260,000 and contains 4 to 7% blowing agent, mostly pentanes or butane usually in Japan. The bead diameter can vary between 0.2mm to 3.0mm [1]. Note that XPS refers to "extruded polystyrene" which is produced by a continuous extrusion process.

EPS is the white foam familiar for its numerous non-geofoam consumer applications such as disposable cups and protective cushion packaging. EPS is often referred to as beadboard since the individual beads can be seen in the final product. XPS geofoam is easily identified by the way that in most countries it is colored for marketing purposes. It is amazing to note that fluorocarbon gases are still used in the production of XPS. Chlorofluorocarbon (CFC) had been used as a blowing agent for many years but now it is banned by international convention for environmental purposes including gases such as hydrochlorofluorocarbon (HCFC) and hydrofluorocarbon (HFC). The blowing agent gas used for EPS and XPS has potential environmental as well as engineering property implications such as the thermal conductivity [2].

EPS is famous for its efficiency, cost-effectiveness, and sanitation. Its lightweight, cushioning, and easy conformity to any shape provide ideal condition for protecting packaged goods during shipping. EPS's efficiency comes from the initial low cost of PS. One of the most obvious advantages EPS or other plastic foams have over coated paper cups or cardboard packaging stuff is that foam insulates better than paper. Life cycle analyses (LCA) suggest that EPS foam holds many other advantages over paper disposables. The analysis finds that the environmental impact from the chemicals and energy used in manufacturing paper goods, as well as the emissions from incinerating or burying papers, well exceeds the impact of producing and disposing of plastic foams [3-6].

Once EPS foam has been used out, its high volume-to-weight ratio becomes a problem, and. it is now prototypical high-bulk/non-burnable landfill problem. This is one of the main obstacles for EPS foam to be recycled. If the EPS foam is delivered to a recycling plant, it can be reproduced easily into various raw materials such as PS pellet, PS resin, and even new EPS through synthetic processing. As with all recycled materials, economic considerations are the most determining factors of successful results. The same properties that make PS a good packing material usually even make it expensive to recycle. The characteristic low density of EPS makes it expensive to ship to a recycling plant [7]. EPS foam is actually 98 percent air by volume. Another obstacle for recycling EPS foam is the surplus of virgin PS, which has let to a decline in the price at which virgin materials are even cheaper, and thus, more attractive to business [8].

In this study, various existing methods to reduce the volume of wasted EPS foam are introduced and discussed in qualitative manner. In many cases, a specific volume reducing method determines the way of post-processing for EPS recycling. The analyses for each method include environmental aspects, cost effectiveness, ease of use, possible post-processing for recycling, physical and chemical degradations of the compacted EPS, advantages and disadvantages for each method, and even the policies of selected countries for wasted EPS foam. To conclude this study, a qualitative comparison table is made to see the facts on recycling wasted EPS foam.

2. Methods of volume reduction

There are many different ways of volume reduction of wasted EPS foams. The methods include thermal processing (compaction by heating), mechanical type compaction, use of toluene or petroleum derived solvents, use of natural solvents, use of far infrared, and pulverization into fine particles simply to reduce the apparent volume. All the methods except pulverization described here can reduce the volume of wasted EPS foam up to 1/50 in net volume and even 1/200 for particular packaging EPS in apparent volume. A particular method for reducing wasted EPS foam is dominantly used since each country has its situation and policy for recycling EPS. Table 1 shows the particular volume reduction methods adopted dominantly in several countries.

Table 1 Popular compaction method in each country

Compaction type	Country
Thermal compaction	Korea, Japan, China
Mechanical compaction	N. America, Europe
Far infrared rays	Japan
Solvents	Japan

2.1 Thermal processing

The thermal compaction process is widely used in Asia, particularly in Korea and Japan. This method is relatively simple such that direct or indirect heating on the wasted EPS foam make it melt down into ingot. Usually, a heat band is used to melt the EPS in direct heating method while heating by friction between EPS's is created during the extrusion into ingot in indirect heating method. There are many other types of thermal compaction facilities. The thermal process is considered to be effective in that it is easy to apply, i.e. low cost facility, but not that low in maintaining cost. However, it generates another environmental problem such as bad odors, and VOCs such as CO_2 emissions and pentane gas. This pentane entrapped in EPS foam, industrially applied as physical blowing agents for the preparation of EPS, have major disadvantages that are harmful to the environment. VOCs such as pentane are precursors for a multitude of other photochemical smog that also have significant environmental consequences [9, 10]. Heat cycle applied to the process of compaction also leads to the degradation of the polymeric properties of PS and the quality of the recycled products is lowered. Thermal compaction method is hardly adopted in the countries in Europe and North America because of this environmental unfriendly process. However, the most common compaction method of EPS foam is the thermal process in Korea. KFRA (Korea Foam-Styrene Recycling Association), founded in 1993, has provided financial support of particular thermal compaction facilities to the local governments, the large distribution stores and even NGOs.

The ingot melt down by a thermal processing is usually to experience another heat cycle to be extruded into PS pellets as a recycled product. The quality of this recycled PS is not expected to be excellent because of many heat cycles. The PS pellets are inexpensive in market and the value added through the recycling process is not so effective in terms of economy. While recycled EPS is also possible in this system simply by applying a blowing agent, the recycled EPS is not sphere form in shape, which may lead to poor mechanical properties in expanded packaging foam due to its irregular shapes in pelletized form. Figure 1 shows the meltdown ingot and recycled PS pellets.

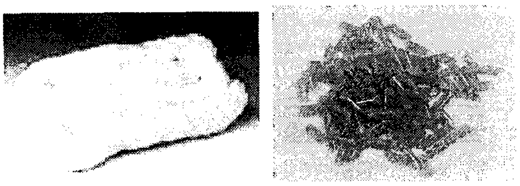


Fig. 1 Meltdown ingot and recycled pellets.

2.2 Processing with petroleum derived solvents

EPS foams are also dissolved with petroleum-derived solvents to reduce volume. Because the properties of PS are degraded by thermal compaction process, the solvent-based approach has been used for reducing EPS volume. However, petroleum-derived solvents such as toluene have safety problems that are toxic and flammable, and environmental problems that are CO_2 emissions, respectively. The solvent/EPS mixture is then transported to a recycling plant where the mixture is usually heated over 200^{o}C to be distilled in a vacuum. The heat cycle applied during distillation may cause breakdown of PS. The applied solvent is evaporated and the separated PS still remains in thick and sticky form at this temperature. Since solvents dissolve only EPS foam, one of advantages of this processing is that it naturally removes any foreign matters such as labels and dust. However, it is not cost effective because of the cost for solvents and of high cost for a distillation plant for recycled PS or EPS in pelletized form. The solvent itself can be recycled in many times only if the solvent is avoided from contamination by other soluble substances which is practically impossible. The solvent/EPS mixture is partly used as a raw material for manufacturing industrial glue.

2.3 Processing with natural derived solvents

Materials mixed with similar molecular structure tend to dissolve each other. This idea led to the use of famous natural solvent, limonene, extracted from orange peel by Sony^{TM} research group [11]. This process is very similar to that with petroleum-derived solvents except the use of natural solvent. The characteristic advantage of this process in reducing wasted EPS foam is that it is not toxic and flammable. However, the use of this natural solvent has not been so popular since the solvent is not cheap enough. During the distillation process to separate the limonene from limonene/PS mixture heat cycle is inevitably applied. Usually, thermal processing has been known to degrade the properties of polymeric materials by breakdown of their molecular characteristics. But it is amazing to note that this is suppressed since limonene oxidizes before PS. Again, the solvent contamination by other soluble substances restricts from recycling the limonene many times. Figure 2 shows how the orange peel dissolves EPS and thereby reduces the volume. This process is used partly in Japan.

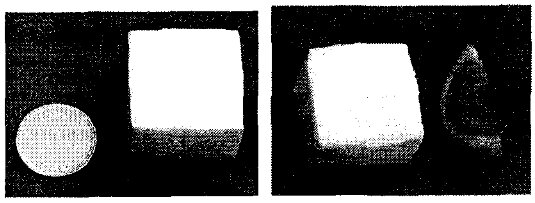


Fig. 2 Orange peel and its dissolubility.

2.4 Use of far infrared rays

Recently, far infrared ray (FIR) is used to shrink the EPS foam in Japan. The infrared rays (IR) can penetrate some materials and naturally generate heat by causing the molecules to rapidly vibrate against each other. When a molecule absorbs radiation, it is raised to an excited state. The excited state may return to its unexcited state simply by dissipating the energy by heat. This happens with longer wave radiation that is turned into heat. If radiation energy is sufficient enough, it may cause a chemical reaction such as de-polymerization and cross-linking, and this frequently results in degradation of the material. However, polymer degradation that results from melting could be avoided since PS does not melt but simply softens under properly controlled situations, i.e. keeping the operating temperature between 120 and 130^{o}C [12]. The avoidance of melting can lead to relatively higher quality recycled products. Each variety of plastic has its own unique peak of IR absorption such that IR energy can heat the plastics selectively. IR wavelength ranges from 770nm (near IR) to 300 μm (far IR). PS can be heated by ceramic emitters at 3.2 μm [13]. However, water absorbs strongly IR above 2.4 μm [14]. This can be a big problem when the wasted EPS is wet or the weather is extremely humid. Also, pre-cleaning is very important for this type of process to be successful. The output is recycled as PS pellets and light-weight concrete.

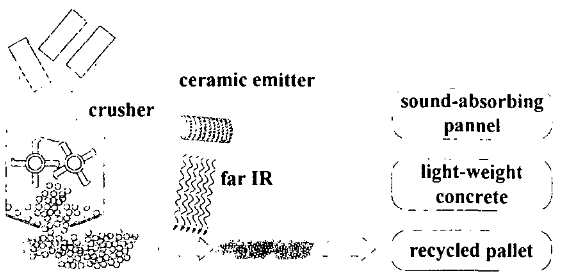
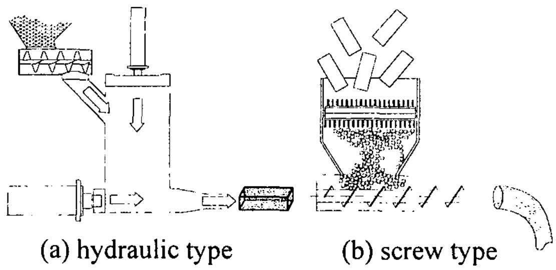


Fig. 3 Shrinking of EPS foam by far infrared rays and its applications.

2.5 Mechanical compaction

Simple mechanical compaction method of wasted EPS foam is widely used in Europe. The methods include two ways: (1) hydraulic cylinder compactors [15] and (2) screw compactors [16]. However, the screw compactor is efficiently utilized only for fine EPS dust while the hydraulic compactors works well even for relatively large size of crushed EPS. The mechanics of this type compaction is to let the entrapped air within the EPS out. However, it is not that simple to regulate the applied pressure or thereby the back pressure induced since the compaction behavior depends much on the conditions such as environmental temperature, humidity, and wasted EPS foam itself. The mechanical compaction usually is cost effective in terms of energy consumption comparing with thermal and solvent processing. This type of compaction is not related to any VOCs emissions and any smells so that it can be environmental friendly. The characteristic advantage of this type compaction is that it does not degrade the PS properties during the volume reduction process since any heat cycle and solvents is not added to the process. Because VOCs is not generated during the process, it is also not harmful to workers operating the facilities. The compact can be recycled as many products. Usually in Europe, it is mostly delivered to chemical plant for synthetic processing to be recycled as a new raw material as EPS [15]. It can be also repelletized for recycled PS product [16]. Recently, a pure mechanical process without any synthetic processing to recycle the compact as a recycled EPS beads has been tested [17]. Figure 4 shows the schematics of mechanical compaction processes, its compact and possibly recycled products. Figure 5 represents a concept of recycling EPS as original raw material mechanically or physically.



(a) hydraulic type (b) screw type

Fig. 4 Mechanical compaction processes.

Comparisons among various methods in volume reduction are shown in Table 2. Each method has its own advantages and also disadvantages.

3. Conclusions and lookout

The conventional volume reduction methods for wasted EPS foam are summarized and compared each other in qualitative manner. Comparison is made among the compaction processes including possible post-processing for recycled products in qualitative sense in terms of environment, economy, and the quality of recycled products. It is concluded from the comparison that the thermal compaction is very simple, but not environmental unfriendly because

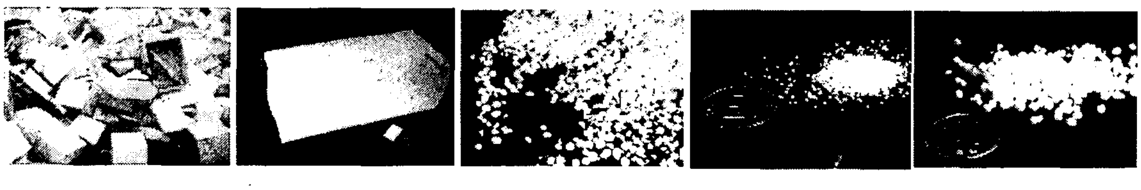


Fig. 5 A possible recycling process with the compact.

Table 2 Qualitative comparisons among volume reduction methods

	Facility cost	Operating cost	Safety of process	Environ. aspects	Degradation of PS by heat cycles	Popular Recycled products	Cost for subsequent EPS mtr'l
Thermal	medium	medium	no good (harmful gas)	VOCs, odors	severe	PS pellets	high
Petro. Solvent	low	high	no good (toxic, inflammable)	VOCs	medium	no significant products	high
Natural solvents	low	extremely high	good	good	medium	PS pellets, EPS pellets	high
Far infrared rays	high	high	good	VOCs	medium	Mostly light-weight concrete	high
Mecha-nical	medium	low	good	good	low	PS pellets, EPS beads	low

of VOCs even during the process. It is not also the beat process for high quality recycled products. Mechanical compaction turns out to be superior to other processes in many aspects. However, if the compact by mechanical process is melted to recycle it as PS pellet, it loses all the advantages arising from mechanical compaction of EPS foam because of polymer degradation. In this paper, a possible method is briefly introduced to recycle the compact from mechanical process directly as recycled EPS beads through purely mechanical, i.e. physical, process. This method may not add any heat cycle through the process to the recycled EPS beads. Further study is needed to complete the process for recycled EPS beads from the compact by mechanical process.

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